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Analysis of the process of cutting the stem with a knife of a disk chopping apparatus

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Abstract. The paper presents the results of the analysis of the process of cutting the stem with a disk-shaped knife, taking into account the physical and mechanical properties of stalk feed. The shell of corn stalks grown in the hot climate of our country is thicker and harder, and its coefficient of friction is somewhat lower. The smaller the angle of friction, the more difficult it is to clamp such a rigid piece of rod between the active and fixed blades. To avoid this condition, the stem must be pinched and sheared between the active blade and the passive blade. On the basis of kinematic studies, the conditions for ensuring the sliding of the rod along the blade of the grinding knife are determined in the work. Based on the physical and mechanical properties of corn stalks, the conditions for ensuring the sliding movement of the stalk along the chopper knife blade are considered.
Key words: stalk, corn, solid body, warm climate, apparatus, blade, active, passive, friction, cutting, machine IKV-F-5A, sliding, punch.

1. Introduction

It is known that the characteristics of crop products grown in the hot climate of Uzbekistan differ from the characteristics of products grown in European conditions. The shell of corn stalks grown for grain in our republic is thicker and harder, and in our experiments it was found that its coefficient of friction with metal is somewhat lower [1]. As a result of initial observations, a part of the corn stalk from the root side (12-15 cm) has a hard shell, which makes it somewhat difficult for the knife blade to penetrate. Due to the fact that the friction angle is less by 3-4°, such a part of the stem does not suddenly stop being pinched between the active and fixed knives, and sliding towards the edge of the fixed knife increases, which makes it difficult to grind such a hard part. To prevent such a situation, we adopted the idea (hypothesis) that it would be better to slightly curve the rectilinear shape of the actual knife blade forward. A number of scientists from foreign countries and in our country conducted research on the theoretical study of the process of grinding stems [2,3,4]. We will carry out a kinematic study of a disk multi-knife grinding apparatus according to the method of prof. S. Melnikova [5].

2. Object and methods of research

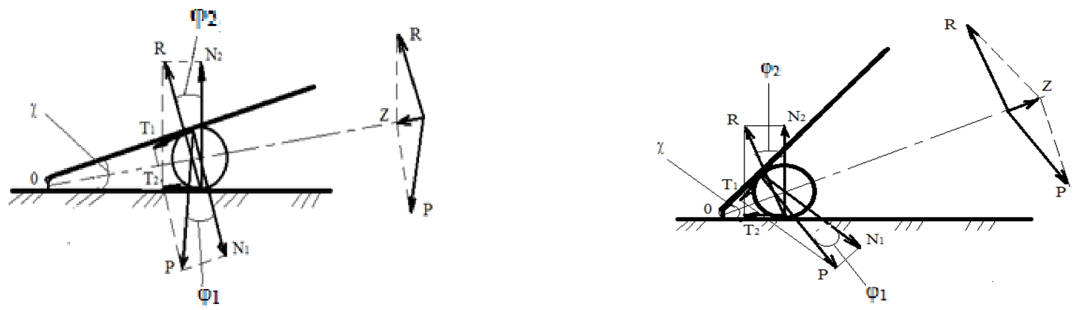
The process of grinding a rough stem is associated with cutting the stem. To grind the stem, it is necessary to ensure that the knife blade slides relative to the stem until we reach its clamping between the active knife blade and the passive knife blade. This can be explained by the diagram in Figure 1.

The pinched blades exert pressure on the body to be ground by normal forces N_1 and N_2. If the angle between the blades χ is less than the sum of the angles of friction between the body and the blades φ_1 and φ_2, i.e.

$$\chi \leq \varphi_1 + \varphi_2 \tag{1}$$

To reduce the deformation of the elastic wedges, the belt needs to make the roller run over the initial section of the belt with a minimum angular velocity, i.e. with a minimum moment of inertia of the compressed body stops there (Figure 1, a), since the friction forces between the blades and the body oppose the outward movement of the body: $T_1 = N_1 f_1$ and $T_2 = N_2 f_2$ are directed towards point 0, due to which the stem cannot withstand the pressure of the blades N_1 and N_2, break the fibers in the bark of the stem and cut off the body.

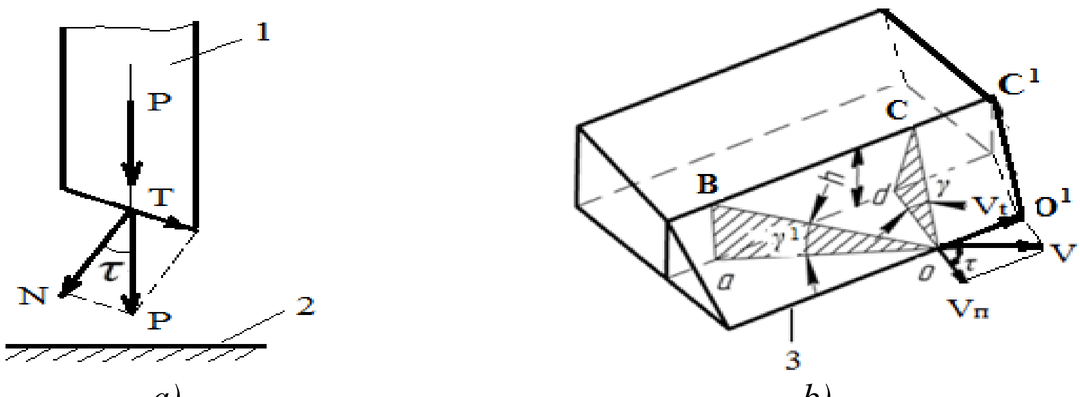
If $\chi > \varphi_1 + \varphi_2$, (Figure 1, c) the force Z acts in the opposite direction and forces the body to come out between the blades. Therefore, the angle χ is called the pinch angle. We will take this rule into account later when determining the dimensions of the knife.



a) b)

Figure 1. Schemes for determining the pinching of the stem between a pair of knives (*a*) and the resulting force Z to push it out of there (*b*)

It is determined that $\chi = 40 - 50°$ for stems grown in European conditions.



a) b)

Figure 2. *a*-the occurrence of a tangential force T to ensure sliding; *b*-position as if a knife is sharpened a lot; 1-knife; 2-cut body; 3-blade

Let us investigate the second condition necessary for a sliding cutting body. Based on the kinematic study, we determine the conditions for ensuring the sliding cutting of the stem along the blade of the chopper knife.

With sliding cutting, firstly, it seems that the geometric parameters of the knife cross section have changed (Figure 2, *b*). In sliding cutting (Figure 2*, a*), if the cut body receives pressure P from the knife and divide it into forces *T* along the blade and *N* along the normal to the blade, then it follows that the angle τ is necessarily less than the angle of friction φ.

With sliding cutting, the knife blade acts on the body not in the *CO* direction, but in the *BO* direction (Figure 2, *b*). As a result, the knife blade seems to be sharpened at an angle γ_1, which is smaller than the angle γ. This ensures that the knife is more easily embedded in the body. In addition, during sliding cutting, the burrs constantly present on the blade, like the teeth of a saw, alternately cut the stem fibers, reducing energy costs. Like an ax, chopping a body uses more energy to cut through all the fibers at once.

The scheme of the improved apparatus is shown in Figure 3. The screw is installed on the disk in the continuation of the shaft. The rectilinear blade of the knives is 20 degrees bent backwards relative to the radial direction. This position provides a sliding cut. The active knife moves along the gap between a pair of fixed knives. A gap of 0.5-1.0 mm is left between active and inactive knives. As a result, the stalk that falls on the fixed knives is cut with a two-support method (Figure 3).

The scheme of two reference cutting and deformations arising in the stem, the acting forces are taken from the works of S.V. Melnikov [5]. The diagram shows the work process as a wedge on both sides of a sharpened knife. In the choppers IKV-F-5A or Volgar-5A studied by us, the blade of the knives is not sharpened (Figure 3, *a*), the thickness of the blade is 5 mm, they form an angle of 90 ° to the sides. This position of the needle causes the stem to be cut to slide along the fixed blades. Such execution of a knife gives the chance on the cut material the sliding movement. As a result, sliding cutting is performed, according to the scheme of Fig. 3*b*, the active knife cuts like a punch [6-15].

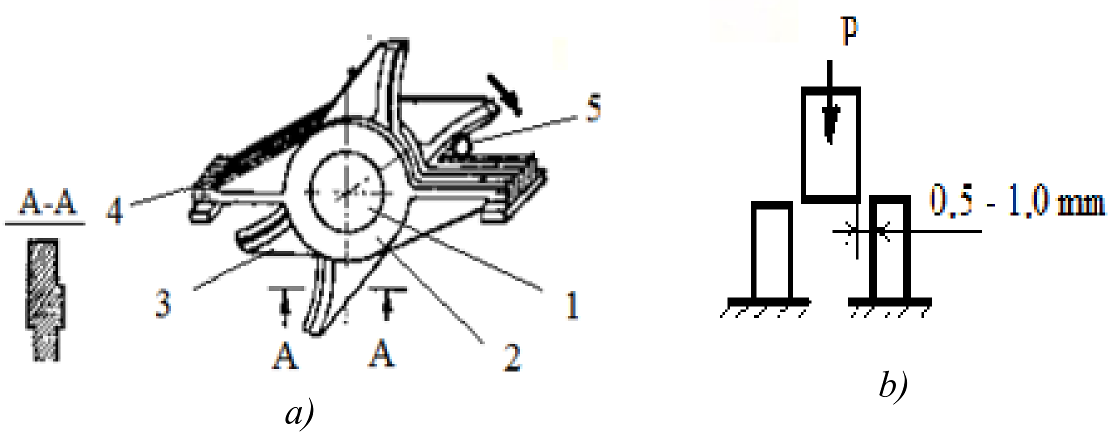


Figure 3. Cutting apparatus of the chopper IKV-F-5A
a-general view; c-scheme of the introduction of an active knife into the gap between passive knives: 1-shaft of the driven pulley; 2-disk; 3-knives installed on the disk; 4-fixed knives and slots created by them; 5-stem pinched between active and passive blades

In our case, we believe that the main factors in cutting the stem are the sliding cutting mode, with the pressure of the blade on the stem. Because our main goal is to grind the rough, tough stalk into small sizes for comfortable eating by animals. To study the process carried out by the disk-shaped multi-knife apparatus under study, we will conduct a kinematic and dynamic study of this apparatus (Figure 4).

3. Research results and discussion

On the pinched stem C between the knife blade, rotating around the axis *O* with a constant angular velocity ω and a stationary passive blade, it acts with normal pressure *N.* If the coefficient of friction between the knife and the stem *f* is known, then the tangential force *T* = *Nf* acts on *C*. Due to the sliding of the knife blade along the stem, the opposite total resistance force *R* will arise, the resultant force *P* acting on *N* and *T*.

Due to the sliding of the knife blade, the resultant force *R* changes its place of action, i.e., the stem *C* changes its position as it slides along the blade from a to b. The minimum radius vector rmin increases with respect to *O* and reaches r max. Thus, even if the magnitude of the resistance forces does not change, due to a change in the force arm r, the moment of resistance on the shaft *M=Rr* increases. The power consumption increases.

Taking this situation into account, we accepted our hypothesis outlined above. In fact, if a very hard and rough stem reaches the end of the blade without breaking, the amount of force N required to break it increases. As a result, *R* also increases and increases the moment *M*. Thus, a sliding cut must be ensured, but the stalk must be cut short of sliding towards the center of the passive knife.

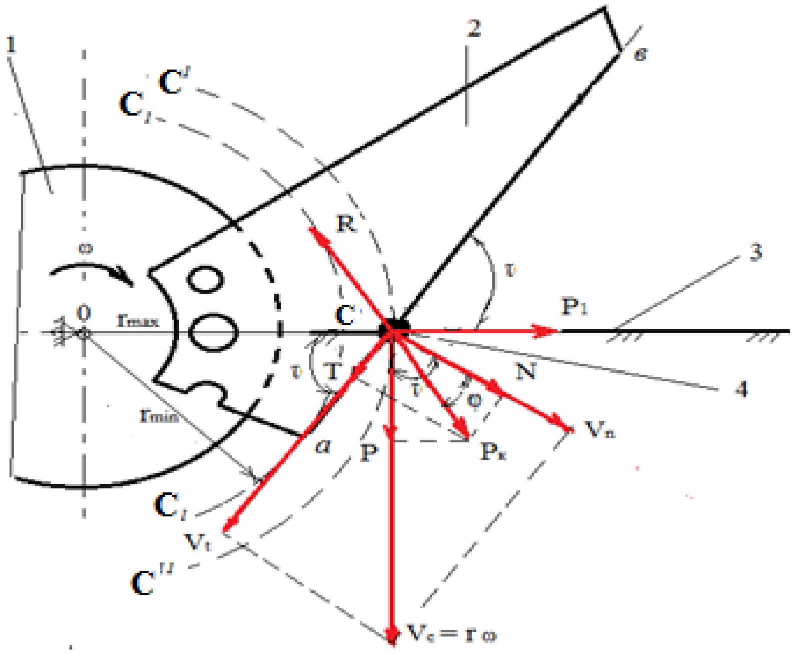


Figure 4. Scheme of the action of the forces of the knife of the grinding apparatus on the stem. 1-knife fixed disc; 2-knife; 3-fixed passive knife; 4-place of the initial meeting of the stem with the knife blade; C_1- at the end of cutting

The sum of the resistance forces arising at point *C* is equal to R, but the knife must act in the opposite direction with the force *Pк*. The rotational force P, component *P к*, is directed perpendicular to the radius vector r. A force P_1 appears, acting in the direction of the radius vector.

Under the action of the rotational force *P*, point C will be shifted along its trajectory C_1-C^{11} , then the force P_1 will press the stem against the passive knife. The angle between the radius vector rmax and the active blade a-b is called the slip angle.

The rotation speed *Vc* =*rω* of point *C* indicates the cutting direction. We find the direction *Vt* along the blade by dividing *Vc* by the normal *Vn* and the tangential velocity *Vt*. If the blade is curved (in our hypothesis it should be a piece of the Archimedean spiral), then the curve Vt will be tangent to the curved blade. The angle between the vectors *Vn* and *Vc* is equal to the glide angle *τ*. That *tg τ* - denotes the ratio of *Vt* to *Vn*, that is, the slip coefficient *Ɛ*:

$$\mathcal{E} = tg\tau = V_t \,/\, V_n \tag{2}$$

The force P_k relative to the force of normal pressure N will be rotated by the angle of friction *φ*. If we divide the force *R* by the normal force *N* and by the tangential force *T* directed along the blade, then the angle between *N* and P_k will be equal to *φ*. Then,

$$T/N = f_1 = \text{tg}\ \varphi. \quad (3)$$

Based on the results of the study, the following conclusions can be drawn.

4. Conclusions

To reduce energy consumption, the blade of the knife should slide over the stem to be cut.

The section on which the resistance force *Rq* acts, acting on the blade as a result of sliding, shifts towards the end of the blade, its shoulder increases relative to the center of the disk, and the torque increases. The resistance acting on the shaft increases.

The knife, working as a punch, not only cuts the bark of the stem, but also grinds the material inside the bark, i.e., does positive work.

The rhizomes of corn stalks grown in hot weather are very hard. The active blade cannot cut it right away. The stem glides over the blade with a long glide. The moment of resistance increases. Therefore, in order to reduce the sliding process when cutting such a stem, it is preferable that the blade be made in the form of an Archimedean spiral directed towards the stem, rather than a straight line.

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